Vacuum Plasma Spray of Cu-8Cr-4Nb for Advanced Liquid-Fuel Combustion Chambers

Marshall Space Flight Center, AL
Glenn Research Center, OH
Plasma Processes Inc., AL

Frank Zimmerman - MSFC
Sandra Elam - MSFC
David Ellis - GRC
Heather Miller - Boeing/RKDN
Timothy McKechnie - PPI
Robert Hickman - PPI

Introduction

- Cu-8Cr-4Nb alloy developed by GRC
  - Intended for use in liquid engine combustion chambers
  - Improved high temp. properties over NARloy-Z
  - Strengthened by fine Cr_2Nb precipitates in Cu matrix
- Vacuum Plasma Spray (VPS) forming advantages
  - Can form near net shape structures vs HIP & extruded
  - Incorporate integral thermal/oxidation barrier, hot wall

Process

- Cu-8Cr-4Nb powder purchased- Crucible Research

Powder	Cr (wt.% / at.%)	Nb (wt.% / at.%)	O (ppm)
MSFC Lot 1	6.45 / 8.00	5.61 / 3.90	1355
MSFC Lot 2	6.79 / 8.33	5.99 / 4.11	805
Special Metals Lot 2	6.35 / 7.79	5.75 / 3.95	468

Process

- Cu-8Cr-4Nb deposited onto mandrels via VPS
- Four post spray processes evaluated
  - As sprayed
  - Four hour vacuum anneal @ 954^{o} C
  - Four hour HIP @ 954^{o} C, 2000 atm
  - Four hour vacuum anneal + one hour HIP
- Measured hardness (Rockwell B) & density

Vacuum Plasma Spray of Cu-8Cr-4Nb for Advanced Liquid-Fuel Combustion Chambers

Process

Condition	Hardness (R_B)	Density (g/cm^3)
As-Sprayed	62.6	8.48
Vacuum Anneal 4hrs @ 954°C	72.3	8.60
HIP 4hrs @ 954°C, 1000 atm	69.3	8.73
Vac. Anneal 4hrs @ 954°C + HIP 1hr/954°C, 1000 atm	76.8	8.73

Note: **theoretical density = 8.4 g/cm^3**

Process

- Tensile test at room temp. & 538^{o} C
- Evaluate effects of oxygen, post processing
- Compare to GRC data for HIP and extruded

Test Data

Processing		0.2% Yield (MPa)	UTS (MPa)	Reduction In Area (%)
VPS + 4 hr HIP @ 954°C	**Avg.**	**179.4**	**197.1**	**26.8**
	σ	2.8	1.4	1.7
LeRC - Extruded	**Avg.**	**165.6**	**183.5**	**44.2**
	σ	1.8	2.5	3.9

Room Temperature Strength for VPS + HIP and Extruded Cu-8Cr-4Nb Material

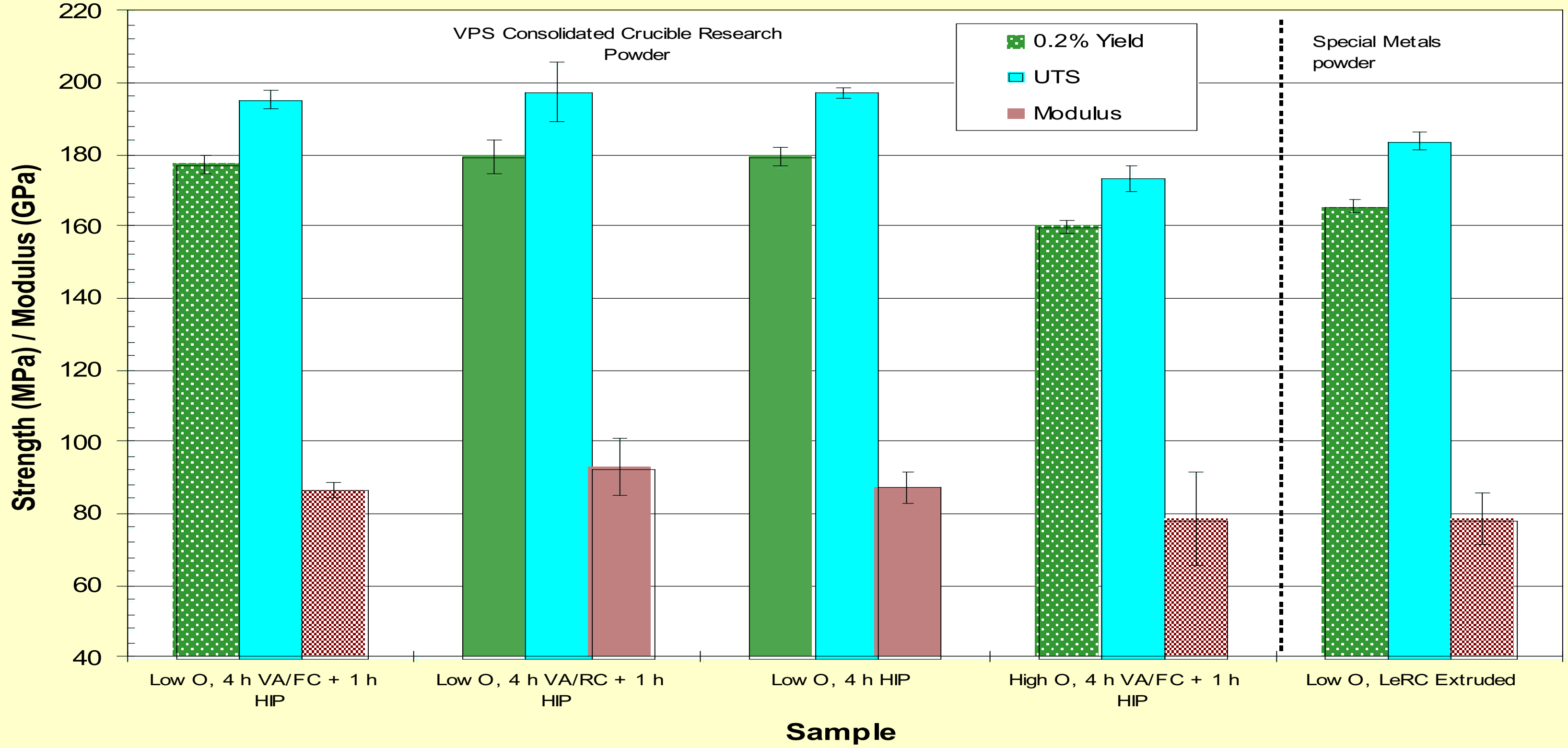
Vacuum Plasma Spray of Cu-8Cr-4Nb for Advanced Liquid-Fuel Combustion Chambers

Test Data

Material	Density (lb_m/ft^3)	Thermal Cond'ty (BTU/in-s-^{0}F) 10^{-3}	Yield Strength @ 1000 ^{0}F (ksi)	Ultimate Strength @ 1000 ^{0}F (ksi)
NARloy-Z	570	4.7	13	17
Cu-8Cr-4Nb (extruded)	543	4.0	17	22
Cu-8Cr-4Nb (VPS formed)	545	4.0	23	27

Vacuum Plasma Spray of Cu-8Cr-4Nb for Advanced Liquid-Fuel Combustion Chambers

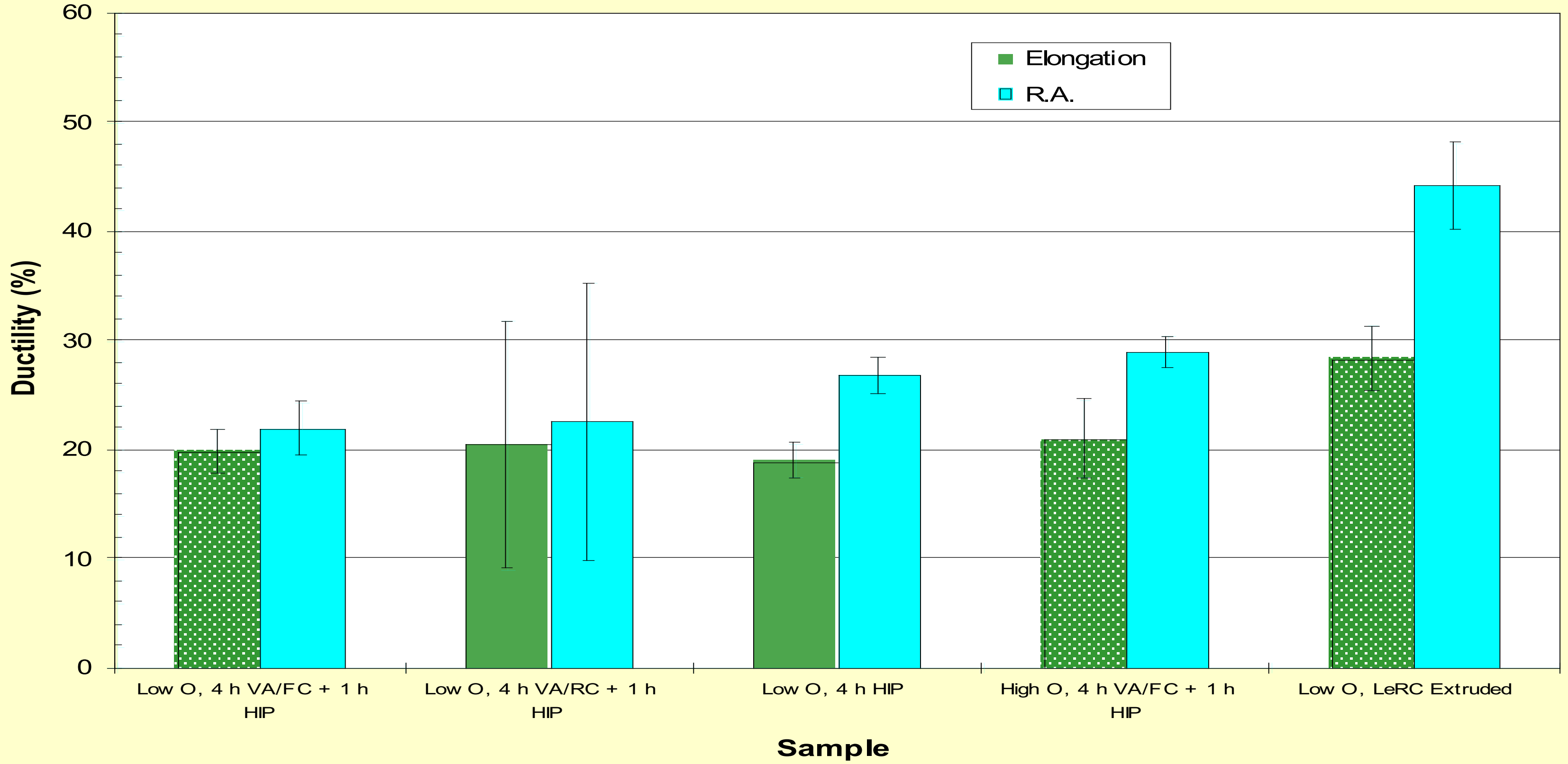
Test Data



Effect of Processing and Oxygen on Strength and Modulus @ 538° C

Vacuum Plasma Spray of Cu-8Cr-4Nb for Advanced Liquid-Fuel Combustion Chambers

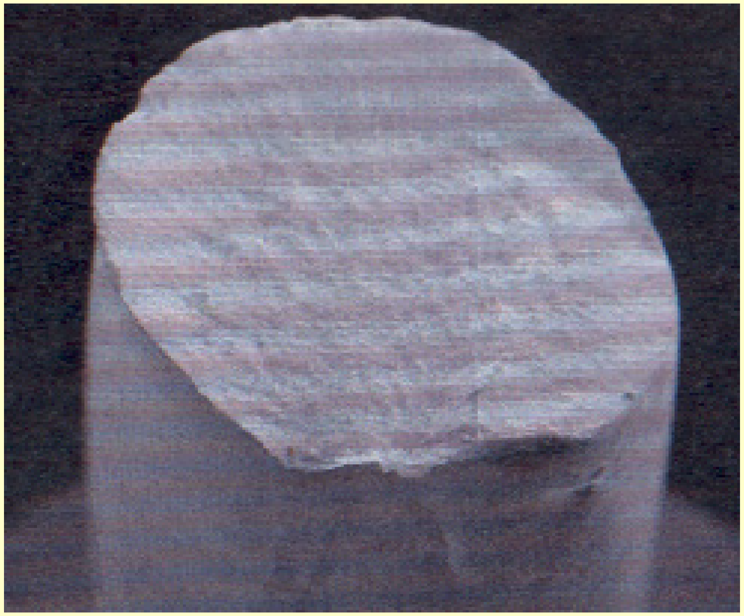
Test Data

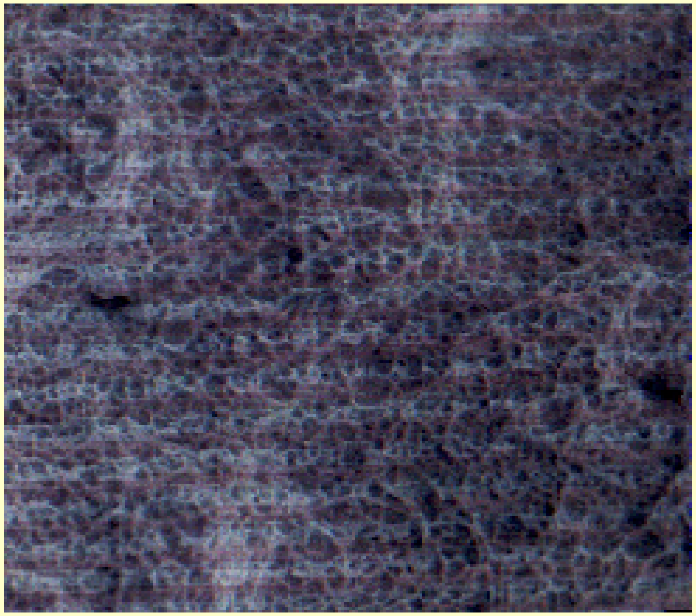


Effect of Processing and Oxygen on Ductility @ 538° C

Vacuum Plasma Spray of Cu-8Cr-4Nb for Advanced Liquid-Fuel Combustion Chambers

Test Data





SEM micrograph of a fracture surface from low oxygen VPS formed Cu-8Cr-4Nb tensile specimens.

15x (left) **1000x (right)**

Applications

- Straight-wall calorimeter spool
  - integral thermal/oxidation coating
  - hot fired at GRC last spring
- Liners for Light Weight Thrust Cells
  - supports NRA work for non-metallic structural jackets
  - novel technique for coolant channel close out

Vacuum Plasma Spray of Cu-8Cr-4Nb for Advanced Liquid-Fuel Combustion Chambers

Applications

VPS formed liner with integral thermal/oxidation barrier coating on hot wall

Applications

- Hot Fire Testing at GRC
  - Chamber pressure = 750 psia
  - Oxygen/Hydrogen ratio = 7.0
  - 15 cycles and 450 seconds
  - Test article hot wall condition rated excellent
  - First demonstration of VPS coating through multiple hot fire cycles

Applications

- Two Liners for Light Weight Thrust Cell
  - PPI formed hot wall portion with CuCrNb
  - Boeing/RKDN closed out cooling channels at MSFC facility
  - Demonstrated water-leached filler for cooling channels
  - Finished liners provided to contractors for application of light weight jacket

Vacuum Plasma Spray of Cu-8Cr-4Nb for Advanced Liquid-Fuel Combustion Chambers

Applications

With filler & ceramic string

After close out

Final machine and leaching

Vacuum Plasma Spray of Cu-8Cr-4Nb for Advanced Liquid-Fuel Combustion Chambers

Applications

Two liners have been provided to contractors for application of graphite fiber and epoxy structural jackets

Cryogenic flow testing complete on first unit (5 cycles LN_2). Hot fire testing to begin end of this year.

Vacuum Plasma Spray of Cu-8Cr-4Nb for Advanced Liquid-Fuel Combustion Chambers

Discussion

- **Vacuum anneal increased hardness and density**
- **Argon quench vs furnace cool showed no effect**
- **Add'l HIP further increased hardness & density**
- **HIPing longer that 1hr showed no add'l benefit**
- **HIPing alone more effective than vacuum anneal**

Discussion

- High oxygen reduces strength, may increase ductility

- Vacuum anneal not effective in abating oxygen effect, as seen in NARloy-Z alloy

Conclusions

VPS formed Cu-8Cr-4Nb alloy, with low oxygen, exhibits higher strength at room and elevated temperature than material formed by extrusion.

The VPS formed material exhibits slightly lower ductility than the extruded material.

VPS forming of Cu-8Cr-4Nb can be used to produce near net structures with mechanical properties comparable to current extruded mat'l

Acknowledgments

The authors would like to thank the Center Director's Discretionary Fund and the Advanced Propulsion Development Office at NASA's Marshall Space Flight Center for their support of this effort.